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Stereoselectivity investigation on glycosylation of oxazolidinone protected 2-amino-2-deoxy-D-glucose donors based on pre-activation protocol

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ABSTRACT

Diverse 2,3-oxazolidinone protected 2-amino-2-deoxy-D-glucose thioglycosides were prepared and studied as glycosyl donors at low temperature by BSM/Tf_2O pre-activation protocol before the addition of glycosyl acceptors. The stereochemistry outcomes of a series of glycosylations were investigated. Different stereoselectivities of the coupling reactions were obtained, arising from the different protecting groups in the oxazolidinone donors. 4,6-Di-*O*-benzyl-*N*-benzyl-oxazolidinone protected thioglycoside donor **1c** underwent glycosylation with general β-anomeric selectivity and the stereoselectivity could be also affected by glycosylation conditions.

1. Introduction

Stereoselective glycosylation for 2-amino-2-deoxy sugars is critical to the assembly of numerous aminosugar-containing oligosaccharides and glycoconjugates with biologically important roles.[1,2] In particular, formation of 1,2-*cis* glycosidic bond, requiring the use of a non-participating group such as an azido group at C-2,[3] is still a challenge to synthetic chemists.[4] In 2001, Kerns and co-workers reported 2,3-*trans*-oxazolidinone as an effective protective group possessing high α-selectivity toward glycosylations.[5a] Unfortunately, this glycosyl donor has several drawbacks such as the undesired glycosylation and sulfenylation of the nitrogen atom. Later, Kerns and co-workers[5b,c] and Oscarson and co-workers[6] modified the oxazolidinone group to its *N*-acetyl analog, leading to significant reduction of α-selectivity, and β-selectivity was observed in some cases. Recently, Ito and co-workers disclosed *N*-benzyl-2,3-*trans*-oxazolidinone as a highly α-directing donor,[7] but the coupling yields are generally not high and the origin of selectivity is not clear. To tackle these problems, a new efficient strategy for both α- and β-stereoselective glycosylations of glucosamine donors based on pre-activation protocol was developed by us very recently.[8] By virtue of the pre-activation strategy,[9,10] that is, a glycosyl donor was pre-activated in the absence of an acceptor, the known 4,6-di-*O*-acetyl-*N*-acetyl-oxazolidinone protected donor **1a** afforded either excellent β-stereoselectivity or excellent α-stereoselectivity toward glycosylations simply by means of the addition of hindered base 2,4,6-tri-*tert*-butylpyrimidine (TTBP)[11] or the absence of base (Fig. 1).

Our initial success suggested that pre-activation protocol could greatly influence the stereochemistry outcomes of glycosylations. Meanwhile, under the conditions of non-preactivation, change and uncertainty in stereochemistry of glycosylations by the use of oxazolidinone and its derivatives as glycosyl donors reported by different research groups[5–7] sparked our curiosity. To explore the scope of pre-activation protocol and investigate the influence of protecting groups at the 4,6-OH and/or 2-NH positions on stereochemistry outcomes toward glycosylations, our attention was paid to stereoselective glycosylations with various oxazolidinone-containing glycosyl donors by pre-activation manner, and our findings are reported here.

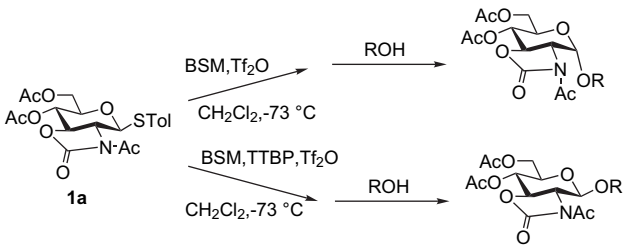

Figure 1. Stereoselectivity-controllable glycosylation of donor **1a**.

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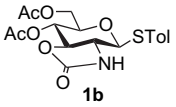
2. Results and discussions

2.1. Preparation of glycosyl donors 1b–1g

A series of oxazolidinone protected glucosamine thioglycosides **1b**–**1g** were designed and synthesized. In these glycosyl donors, the 4,6-OH and 2-NH functional groups were protected by two kinds of groups: the electron-donating benzyl group (or benzylidene group) and the electron-withdrawing acetyl group. Among them, **1b** is known and was prepared according to the literature.[5c]



1b

The synthesis of *N*-benzyl-oxazolidinone protected glycosyl donors **1c**, **1f** and **1g**, *N*-acetyl-oxazolidinone protected glycosyl donor **1e** and *N*-unsubstituted-oxazolidinone protected glycosyl donor **1d** all started from the same glucosamine derivative **2**[12] (Scheme 1). Removal of the acetyl groups in **2** with 30% MeONa afforded the intermediate **3** in quantitative yield. Compound **3** was treated with sodium hydride (NaH) and benzyl bromide (BnBr) to provide 4,6-di-*O*-benzyl-*N*-benzyl-2*N*,3*O*-oxazolidinone protected donor **1c** and 4,6-di-*O*-benzyl-2*N*,3*O*-oxazolidinone protected donor **1d**, respectively, just by using different amount of the benzylation reagents (6.0 equiv of NaH and 4.5 equiv of BnBr for **1c**; 4.5 equiv of NaH and 2.5 equiv of BnBr for **1d**). The reaction outcomes can be modulated because the O-benzylation occurs ahead of the N-benzylation. The *N*-acetyl donor **1e** was easily prepared via acetylation of donor **1d**. On the other hand, compound **3** was subjected to 4,6-*O*-benzylidene protection to afford **4**, which was treated again with NaH and BnBr, yielding the *N*-benzyl donor **1f** in good isolated yield. Subsequently, **1f** was smoothly converted to **1g** via selective deprotection followed by re-acetylation.

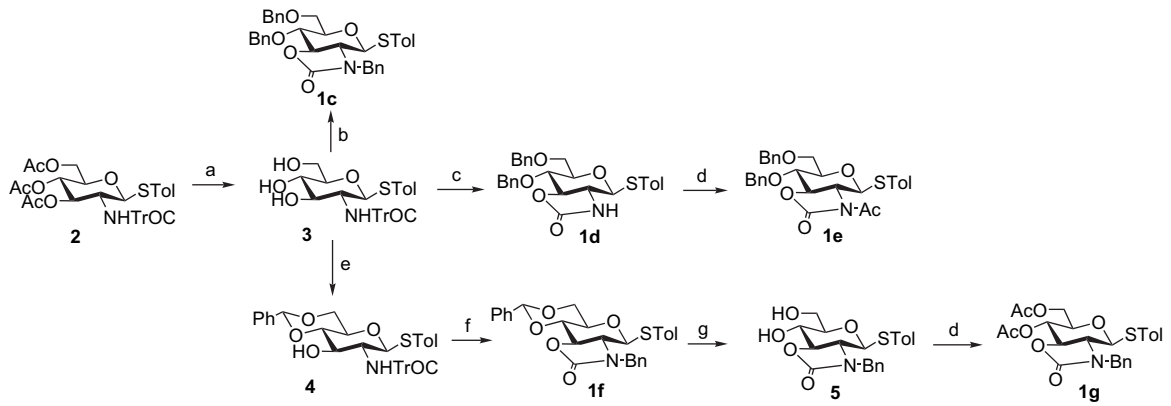
2.2. Glycosylations of various 2,3-oxazolidinone protected glycosyl donors with unalterable acceptor 6a

With glycosyl donors **1b**–**1g** in hand, we firstly investigated the influence of protecting groups at the 4,6-OH and/or 2-NH positions on stereochemistry outcomes toward glycosylations. A series of couplings of the unalterable acceptor **6a** with diverse donors **1b**–**1g** by pre-activation protocol were checked (Table 1). Identical to our previous work,[8] a combination of benzenesulfinyl morpholine (BSM)[13] and triflic anhydride (Tf_2O) acted as the promoter system. Since the use of hindered base is not necessary in our routine pre-activation protocol,[9,13] the glycosylation reactions were conducted in the absence of hindered base TTBP. Each donor was pre-activated by BSM/Tf_2O at low temperature in anhydrous CH_2Cl_2, the acceptor **6a** was then added to the reaction mixture after the complete consumption of donor by TLC monitoring. As shown in Table 1, glycosyl donors **1b**, **1c**, **1e** and **1g** successfully afforded the coupling products in good isolated yields,[14] but interestingly, the stereoselectivities varied with the glycosyl donors equipped with different protecting groups. Among them, the tri-benzyl substituted donor **1c** exhibited complete β-selectivity (entry 2). Compared with 4,6-di-*O*-acetyl-*N*-acetyl-oxazolidinone protected donor **1a** reported in our previous work, glycosyl donor **1c** afforded the completely opposite stereochemistry outcomes under the same glycosylation conditions. It showed that the stereoselectivities of glycosylations by pre-activation protocol can be modulated by suitably protected glycosyl donors.

The different stereoselectivities might arise from the variety of intermediates. After being activated, the oxazolidinone protected donors turned into the oxacarbenium ion, which could be trapped by triflate anion to give either α-triflate or β-triflate.[15] Thus, under pre-activation conditions, there are three types of intermediate: oxacarbenium ion, α-triflate and β-triflate. Oxacarbenium ion intermediate may participate in an S_N1-like process with the acceptor, while triflate intermediate may participate in an S_N2-like process. The electronic property of protecting groups may influence the major form of intermediate during the glycosylation reactions. Pre-activation of 4,6-*O*-benzyl protected donors **1c** and **1e** (entries 2 and 4, Table 1) produced oxacarbenium ions, which could be the major form existed instead of the glycosyl triflate presumably due to the stabilization effect of electron-donating benzyl groups. Attacked by acceptor **6a** via an S_N1-like process, the disaccharides **7c** and **7e** were gained. The only discrimination between **1c** and **1e** is the protecting group at 2-N-position. *N*-Benzyl group affords steric hindrance to α-face attack by hindered nucleophiles, and results in excellent β-selectivity. This steric hindrance is removed in the case of *N*-acetyl substituent, so there is no selectivity for donor **1e**. Pre-activation of 4,6-*O*-acetyl protected donors **1b** and **1g** (entries 1 and 6, Table 1) could afford glycosyl triflates by contrast. The equilibrium might favor the formation of covalent anomeric triflates in this case because the oxacarbenium ion could be very unstable and be trapped easily by triflate anion, arising from the electron-withdrawing effect of acetyl groups. Both α-triflate and β-triflate may exist, so the coupling products are α/β-anomeric mixtures.

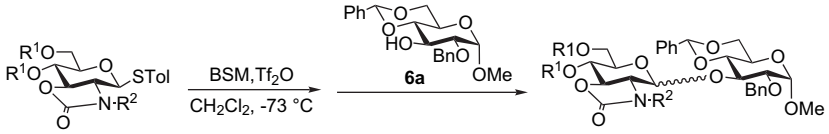
2.3. Stereoselective couplings of donor 1c with various glycosyl acceptors

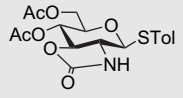
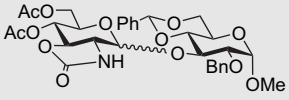
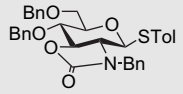
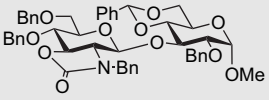
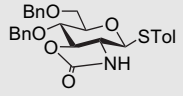
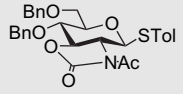
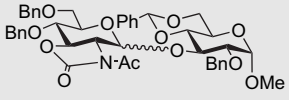
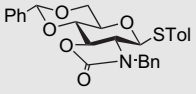
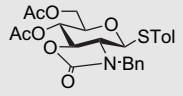
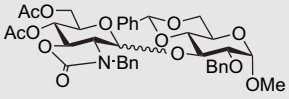
Based on the excellent β-stereoselectivity of coupling between donor **1c** and acceptor **6a**, we then focused on performing



Scheme 1. Preparation of donors **1c**–**1g**. Reagents and conditions: (a) MeONa, MeOH, 100%; (b) 4.5 equiv BnBr, 6.0 equiv NaH, DMF, 80%; (c) 2.5 equiv BnBr, 4.5 equiv NaH, DMF, 65%; (d) Ac_2O, Py, 95% for **1e**, 90% for **1g**; (e) $PhCH(OMe)_2$, CSA, CH_3CN, 85%; (f) 1.5 equiv BnBr, 2.5 equiv NaH, DMF, 90%; (g) TsOH, MeOH, 85%.

Table 1
The couplings of various 2,3-oxazolidinone protected glycosyl donors with unalterable acceptor **6a**



Entry	Donor	T (°C)	Product	Yield (%)	α/β
1	 **1b**	−73	 **7b**	87	1:2
2	 **1c**	−73	 **7c**	85	β only
3	 **1d**	−73	No coupling product		
4	 **1e**	−60	 **7e**	84	1:1[a]
5	 **1f**		No activation		
6	 **1g**	−50	 **7g**	94	3:1

[a] Anomeric ratio was determined by the integration of ^{1}H NMR spectrum of the anomeric mixture.

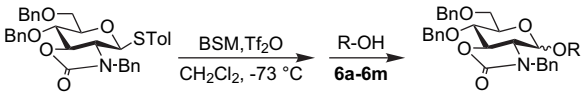
glycosylations of **1c** with a series of acceptors by pre-activation manner to illustrate the generality of the stereoselectivity, and the results are listed in Table 2. As shown, donor **1c** was β-selective toward glycosylations with a wide range of glycosyl acceptors except for acceptor **6m** (entry 13) and the coupling yields were generally high. And a clear trend that the stereochemistry outcomes of the glycosylations correlated to acceptors was observed. Acceptors **6a**–**6e** equipped with 4,6-*O*-benzylidene protecting group displayed excellent β-selectivity (entries 1–5), and more reactive acceptors **6i** and **6j** with primary hydroxyl group also led to good β-selectivity (entries 9 and 10). In contrast to the recently reported similar donor *N*-benzyl-2,3-*trans* oxazolidinone derivative,[7] our donor **1c** provided opposite stereoselectivity under pre-activated conditions. It is again verified that pre-activation protocol can influence the stereoselectivity of glycosylations.

According to the results displayed in Table 2, the glycosylation might be an S_N1-like process via the intermediate of oxacarbenium ion. The benzyl group on nitrogen atom affords steric hindrance to α-face attack by hindered nucleophiles. Thus the glycosylation reaction is β-selective, more hindered acceptors equipped with the 4,6-*O*-benzylidene protecting group afford better stereoselectivity. In comparison with donor **1a**,[8] the opposite stereoselectivity of donor **1c** may arise from the different intermediates produced after pre-activation, which could be influenced by the electronic property of protecting groups at the 4,6-OH and 2-NH positions.

2.4. Stereochemistry under different glycosylation conditions

Next we turned our attention to the influence on stereochemistry outcomes arising from different glycosylation conditions such as solvent, temperature and promoter system. The representative reaction was performed as exemplified by the coupling of donor **1c** and acceptor **6a** (Table 3). In contrast to our published work,[8] addition of the hindered base TTBP to the reaction system gave rise to the same stereoselectivity in a little higher yield (entry 1). Under pre-activation conditions, using benzenesulfinyl piperidine/triflic anhydride (BSP/Tf_2O)[16] or diphenyl sulfoxide/triflic anhydride (Ph_2SO/Tf_2O)[17] instead of our BSM/Tf_2O promoter system, the coupling afforded almost the same results (entry 2). However, activation of thioglycoside **1c** by employing *N*-(phenylthio)-ε-caprolactam/Tf_2O[18] or NIS/AgOTf[19] led to non-stereoselective glycosylation, providing both α- and β-linked products (entries 3–6). The quotient of α-anomer increased along with rise of temperature (entry 3 vs entry 4). Change of solvent from CH_2Cl_2 to toluene also led to the increase of α-anomer (entry 3 vs entry 5). It was exhibited that stereochemistry outcomes of glycosylations can be modulated by reaction conditions such as promoter, temperature, solvent and activation manner. The rise of temperature and the use of non-polar solvent resulted in the increase of the thermodynamic-controlled product α-anomer.

Table 2
Glycosylations of donor **1c** with a series of acceptors by BSM/Tf_2O pre-activation



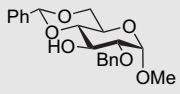
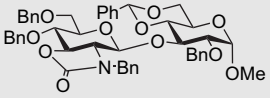
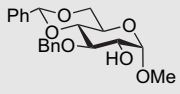
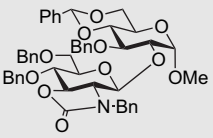
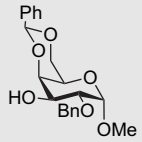
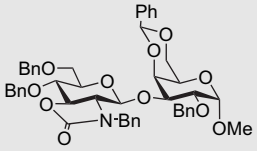
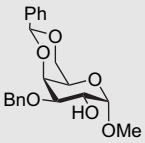
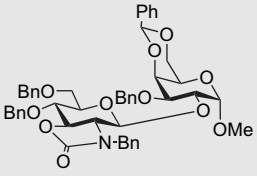
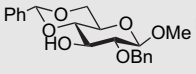
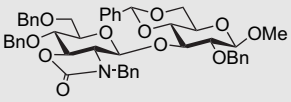
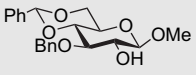
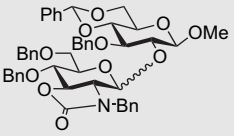
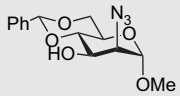
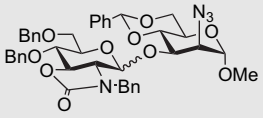
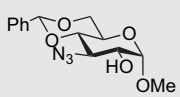
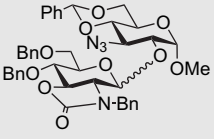
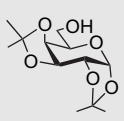
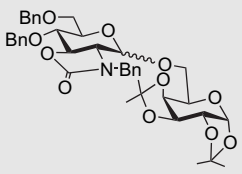
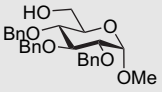
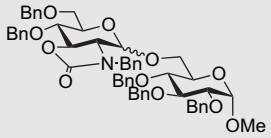
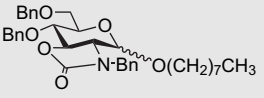
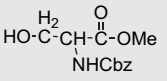
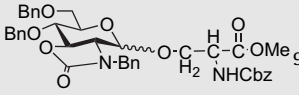
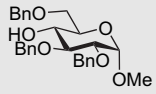
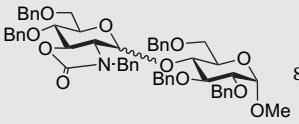
Entry	Acceptor (ROH)	Product	Isolated yield (%)	Anomeric ratio (α/β)
1	 **6a**	 **7c**	85	β only
2	 **6b**	 **8b**	83	β only
3	 **6c**	 **8c**	83	β only
4	 **6d**	 **8d**	84	β only
5	 **6e**	 **8e**	87	β only
6	 **6f**	 **8f**	85	1:2 [a]
7	 **6g**	 **8g**	83	1:1.5
8	 **6h**	 **8h**	91	1:2
9	 **6i**	 **8i**	96	1:11[a]

Table 2 (*continued*)

Entry	Acceptor (ROH)	Product	Isolated yield (%)	Anomeric ratio (α/β)
10	 **6j**	 **8j**	85	1:6[a]
11	$CH_3(CH_2)_7OH$ **6k**	 **8k**	95	1:3.5
12	 **6l**	 **8l**	98	1:3[a]
13	 **6m**	 **8m**	82	2.5:1[a]

[a] Anomeric ratio was determined by the integration of ^1H NMR spectrum of the anomeric mixture.

2.5. Deprotection of disaccharide 8d

The formed disaccharides can be fully deprotected. For example, as shown in Scheme 2, disaccharide **8d** was deprotected under basic conditions (*t*-BuOK/DMSO).[20] The ring-fused oxazolidinone was thus opened in several minutes in excellent yield affording **9**, followed by the concomitant removal of the *O*-, *N*-benzyl groups and *O*-benzylidene group over hydrogenolysis to obtain disaccharide **10**.

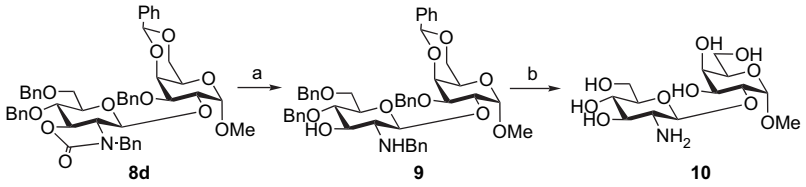
3. Conclusion

We have demonstrated that diverse 2,3-oxazolidinone protected 2-deoxy-2-amino-D-glucose thioglycosides show different even opposite stereoselectivities in glycosylations conducted by the BSM/Tf_2O pre-activation protocol at low temperature in dichloromethane. The stereochemistry outcomes of coupling reactions are strongly influenced by the protecting groups in oxazolidinone protected glycosyl donors and the activation manner of donors. In contrast to the tri-acetyl protected donor **1a** reported previously, 4,6-di-*O*-benzyl-*N*-benzyl-oxazolidinone protected thioglycoside donor **1c** affords moderate to excellent β-selectivity toward glycosylations. Moreover, in the case of donor **1c**, the stereoselectivity

Table 3
The coupling of donor **1c** and acceptor **6a** under different conditions

Entry	Promoter system	Solvent	Temperature (°C)	Isolated yield (%)	Anomeric ratio (α/β)
1	BSM, TTBP, Tf_2O	CH_2Cl_2	−73	88	βonly
2	BSP (or Ph_2SO), Tf_2O	CH_2Cl_2	−73	85–87	βonly
3	*N*-(Phenylthio)-ε-caprolactam, Tf_2O	CH_2Cl_2	15	86	1:1.5[a]
4	*N*-(Phenylthio)-ε-caprolactam, Tf_2O	CH_2Cl_2	45	75	1:1[a]
5	*N*-(Phenylthio)-ε-caprolactam, Tf_2O	Toluene	15	87	1:1[a]
6	NIS/AgOTf	CH_2Cl_2	−10	86	1:2.5[a]

[a] Anomeric ratio was determined by the integration of ^1H NMR spectrum of the anomeric mixture.



Scheme 2. Deprotection of disaccharide **8d**. Reagents and conditions: (a) *t*-BuOK, DMSO, 90%; (b) H_2, Pd/C, 95%.

cannot be affected by the addition of TTBP, but can be modulated by changing reaction conditions such as solvent, temperature and promoter system. In summary, based on our BSM/Tf_2O pre-activation strategy, using 2,3-oxazolidinone protected thioglycoside donors, either α- or β-glycosidic linkage can be formed. The stereoselectivity can be greatly affected by modulating protective groups of the glycosyl donors. The mechanistic understandings await further investigation.

4. Experimental

4.1. General procedures

All chemicals were purchased as reagent grade and used without further purification, unless otherwise noted. Dichloromethane (CH_2Cl_2), pyridine, toluene and acetonitrile (CH_3CN) were distilled over calcium hydride (CaH_2). Methanol was distilled from magnesium. DMF was stirred with CaH_2 and distilled under reduced pressure. All reactions were carried out under anhydrous conditions with freshly distilled solvents, unless otherwise noted. Reactions were monitored by analytical thin-layer chromatography on silica gel 60 F254 precoated on aluminum plates (E. Merck). Spots were detected under UV (254 nm) and/or by staining with acidic ceric ammonium molybdate. Solvents were evaporated under reduced pressure and below 40 °C (bath). Organic solutions of crude products were dried over anhydrous Na_2SO_4. Column chromatography was performed on silica gel (200–300 mesh). ^1H NMR spectra were recorded on a JEOL AL-300, Varian INOVA-500, or Advance DRX Bruker-500 spectrometers at 25 °C. Chemical shifts (in ppm) were referenced to tetramethylsilane (δ=0 ppm) in deuterated chloroform. ^{13}C NMR spectra were obtained by using the same NMR spectrometers and were calibrated with $CDCl_3$ (δ=77.00 ppm). Mass spectra were recorded using a PE SCLEX QSTAR spectrometer. Elemental analysis data were recorded on a Vario EL-III elemental analyzer.

4.2. Preparation of oxazolidinone protected glycosyl donors

*4.2.1. p-Tolyl N-2,2,2-trichloroethyloxycarbonyl-2-amino-2-deoxy-1-thio-β-D-glucopyranoside (**3**)*

Trichloroethyl carbamate protected glucosamine **2** (2.00 g, 3.41 mmol, 1 equiv) in 100 mL methanol containing a catalytic amount of NaOMe (30% in MeOH) under pH 8–9 was stirred for 1.5 h. The reaction mixture was neutralized with cation exchange resin (H^+), filtered and concentrated to dryness under reduced pressure to give compound **3** (1.50 g, 95%) as a white solid. R_f=0.7 (ethyl acetate/methanol, 10:1). Compound **3** was used for the next reaction directly.

*4.2.2. p-Tolyl N-benzyl-2-amino-2,3-N,O-carbonyl-4,6-O-dibenzyl-2-deoxy-1-thio-β-D-glucopyranoside (**1c**)*

Compound **3** (1.50 g, 3.26 mmol, 1 equiv) was dissolved in dry DMF (40 mL) and stirred at −15 °C, and NaH (0.78 g, 19.57 mmol, 6 equiv, 60% in mineral oil) was added, followed by the addition of benzyl bromide (1.75 mL, 14.67 mmol, 4.5 equiv). After stirring for 30 min on the ice-water bath, the reaction mixture was warmed to room temperature and stirred for 4 h. The mixture was directly concentrated under reduced pressure, and the residue was purified by column chromatography (petroleum ether/ethyl acetate, 12:1) to give **1c** (1.51 g, 80%) as a white solid: ^1H NMR (500 MHz, $CDCl_3$) δ 7.24–7.41 (m, 17H), 7.00 (d, 2H, *J*=8.0 Hz), 4.88 (d, 1H, *J*=11.5 Hz), 4.78 (d, 1H, *J*=15.0 Hz), 4.74 (d, 1H, *J*=15.0 Hz), 4.69 (d, 1H, *J*=9.5 Hz, H-1), 4.55 (d, 1H, *J*=11.5 Hz), 4.54 (d, 1H, *J*=11.5 Hz), 4.48 (d, 1H, *J*=12.0 Hz), 4.16 (dd, 1H, *J*=10.0, 11.0 Hz), 3.86 (dd, 1H, *J*=8.5, 9.5 Hz), 3.75 (dd, 1H, *J*=2.0, 11.0 Hz), 3.69 (dd, 1H, *J*=5.0, 11.0 Hz), 3.54–3.57 (m, 1H), 3.44 (dd, 1H, *J*=9.5, 11.0 Hz), 2.29 (s, 3H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 159.27, 138.61, 138.06, 137.32, 136.36, 132.93, 129.80, 128.63, 128.48, 128.39, 128.33, 128.16, 128.00, 127.93, 127.70, 127.62, 127.57, 86.64, 83.45, 79.91, 73.74, 73.38, 73.16, 68.53, 60.30, 47.46, 21.10; MS (FAB) 581 $[M]^+$; Anal. Calcd for $C_{35}H_{35}NO_5S$: C, 72.26; H, 6.06; N, 2.41. Found: C, 72.37; H, 6.15; N, 2.31.

*4.2.3. p-Tolyl 2-amino-2,3-N,O-carbonyl-4,6-O-dibenzyl-2-deoxy-1-thio-β-D-glucopyranoside (**1d**)*

Compound **3** (1.50 g, 3.26 mmol, 1 equiv) was dissolved in dry DMF (30 mL) and stirred at −15 °C, and NaH (0.59 g, 14.67 mmol, 4.5 equiv, 60% in mineral oil) was added, followed by the addition of benzyl bromide (0.97 mL, 8.15 mmol, 2.5 equiv). After stirring for 30 min on the ice-water bath, the reaction mixture was warmed to room temperature and stirred for 2 h. The mixture was directly concentrated under reduced pressure, and the residue was purified by column chromatography (petroleum ether/ethyl acetate, 5:1) to give the major product **1d** (1.04 g, 65%) as a white solid: ^1H NMR (500 MHz, $CDCl_3$) δ 7.28–7.41 (m, 10H), 7.15–7.17 (m, 2H), 7.07–7.09 (m, 2H), 4.91 (d, 1H, *J*=11.5 Hz), 4.78 (s, 2H), 4.72 (d, 1H, *J*=9.5 Hz, H-1), 4.61 (d, 1H, *J*=11.0 Hz), 4.18 (dd, 1H, *J*=10.0, 11.0 Hz), 3.80–3.85 (m, 2H), 3.69–3.74 (m, 1H), 3.45–3.48 (m, 1H), 3.36 (dd, 1H, *J*=9.5, 11.5 Hz), 2.32 (s, 3H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 159.21, 139.03, 137.20, 136.21, 133.06, 129.94, 128.70, 128.50, 128.15, 128.05, 127.65, 86.70, 83.19, 80.19, 73.49, 73.22, 61.60, 60.43, 47.52, 21.12; HRMS (ESI) calcd for $C_{28}H_{30}NO_5S$ $[M+H]^+$: 492.1839, found: 492.1826.

*4.2.4. p-Tolyl N-acetyl-2-amino-2,3-N,O-carbonyl-4,6-O-dibenzyl-2-deoxy-1-thio-β-D-glucopyranoside (**1e**)*

To a stirred solution of the compound **1d** (0.50 g, 1.02 mmol, 1 equiv) in pyridine (10 mL), was added acetic anhydride (0.29 mL, 3.05 mmol, 3 equiv). The reaction mixture was stirred at room temperature for 2 h, quenched by the addition of saturated aqueous $NaHCO_3$ (15 mL) and extracted with CH_2Cl_2 (2×15 mL). The combined organic layer was dried, filtered and concentrated under reduced pressure. The residue was purified by column chromatography (petroleum ether/ethyl acetate, 5:1) to give **1e** (0.51 g, 95%) as a white solid: ^1H NMR (500 MHz, $CDCl_3$) δ 7.28–7.42 (m, 10H), 7.21–7.23 (m, 2H), 7.07 (d, 2H, *J*=8.0 Hz), 4.90 (d, 1H, *J*=11.5 Hz), 4.49 (d, 1H, *J*=15.5 Hz), 4.75 (d, 1H, *J*=16.0 Hz), 4.66 (d, 1H, *J*=9.5 Hz, H-1), 4.59 (d, 1H, *J*=11.5 Hz), 4.30 (dd, 1H, *J*=2.5, 12.0 Hz), 4.25 (dd, 1H, *J*=5.0, 12.0 Hz), 4.16 (dd, 1H, *J*=9.5, 11.0 Hz), 3.74 (t, 1H, *J*=9.5 Hz), 3.58–3.61 (m, 1H), 3.40 (dd, 1H, *J*=9.5, 11.5 Hz), 2.33 (s, 3H), 1.96 (s, 3H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 170.49, 159.08, 138.91, 136.93, 136.29, 133.24, 129.78, 128.67, 128.51, 128.28, 128.19, 128.14, 127.63, 86.69, 83.37, 77.76, 73.05,

72.96, 62.74, 60.30, 47.49, 21.13, 20.75; HRMS (ESI) calcd for $C_{30}H_{31}NO_6SNa$ $[M+Na]^+$: 572.1504, found: 572.1506.

4.2.5. *p*-Tolyl N-2,2,2-trichloroethyloxycarbonyl-2-amino-4,6-O-benzylidene-2-deoxy-1-thio-β-D-glucopyranoside (**4**)

Compound **3** (1.50 g, 3.26 mmol, 1 equiv) in CH_3CN (40 mL) containing a catalytic amount of camphorsulfonic acid under PH 2–3 was stirred, followed by the addition of benzaldehyde dimethyl acetyl (0.59 mL, 3.91 mmol, 1.2 equiv). The mixture was stirred for 5 h, then neutralized with Et_3N and concentrated to dryness under reduced pressure. The crystalline residue was crystallized from EtOAc to give **4** (1.52 g, 85%) as a white solid. The NMR data of **4** was identical to that reported previously.[9b]

4.2.6. *p*-Tolyl N-benzyl-2-amino-4,6-O-benzylidene-2,3-N,O-carbonyl-2-deoxy-1-thio-β-D-glucopyranoside (**1f**)

Compound **4** (1.00 g, 1.82 mmol, 1 equiv) was dissolved in dry DMF (15 mL) and stirred at −15 °C, and NaH (0.18 g, 4.56 mmol, 2.5 equiv, 60% in mineral oil) was added, followed by the addition of benzyl bromide (0.33 mL, 2.74 mmol, 1.5 equiv). After stirring for 30 min on the ice-water bath, the reaction mixture was warmed to room temperature and stirred for 2 h. The mixture was directly concentrated under reduced pressure, and the residue was purified by column chromatography (petroleum ether/ethyl acetate, 10:1) to give the main product **1f** (0.89 g, 90%) as a white solid: ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.43–7.26 (m, 10H), 7.11–7.07 (m, 4H), 5.73 (s, 1H), 5.28 (d, J=9.5 Hz, 1H), 4.71–4.66 (m, 2H), 4.59 (d, J=11.5 Hz, 1H), 4.25–4.20 (m, 2H), 3.86 (t, J=10.5 Hz, 1H), 3.74–3.69 (m, 1H), 3.67 (t, J=10.5 Hz, 1H), 2.26 (s, 3H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 158.6, 137.7, 17.4, 137.0, 131.4, 129.8, 129.1, 128.6, 128.4, 128.2, 127.0, 100.2, 85.8, 77.5, 71.5, 67.4, 61.3, 47.4, 20.6; HRMS (ESI) calcd for $C_{28}H_{28}NO_5S$ $[M+H]^+$: 490.1683, found: 490.1682.

4.2.7. *p*-Tolyl N-benzyl-2-amino-2,3-N,O-carbonyl-2-deoxy-1-thio-β-D-glucopyranoside (**5**)

Compound **1f** (0.50 g, 1.02 mmol, 1 equiv) was dissolved in methanol (15 mL) and stirred, then TsOH (0.10 g, 0.51 mmol, 0.5 equiv) was added. The reaction mixture was stirred over night, then neutralized with Et_3N and concentrated to dryness under reduced pressure to give compound **5** (0.35 g, 86%) as a white solid. R_f=0.1 (petroleum ether/ethyl acetate, 10:1). Compound **5** was used for the next reaction directly.

4.2.8. *p*-Tolyl N-benzyl-2-amino-2,3-N,O-carbonyl-4,6-O-diacetyl-2-deoxy-1-thio-β-D-glucopyranoside (**1g**)

To a stirred solution of compound **5** (0.35 g, 0.87 mmol, 1 equiv) in pyridine (10 mL), was added acetic anhydride (0.82 mL, 8.71 mmol, 10 equiv). The reaction mixture was stirred at room temperature for 3 h, quenched by the addition of saturated aqueous $NaHCO_3$ (15 mL) and extracted with CH_2Cl_2 (2×15 mL). The combined organic layer was dried, filtered and concentrated under reduced pressure. The residue was purified by column chromatography (petroleum ether/ethyl acetate, 3:1) to give **1g** (0.38 g, 90%) as a white solid: ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.23–7.41 (m, 7H), 7.09 (d, 2H, J=8.0 Hz), 5.24 (dd, 1H, J=9.0, 10.0 Hz), 4.76 (s, 2H), 4.71 (d, 1H, J=9.6 Hz, H-1), 4.10–4.26 (m, 3H), 3.67–3.73 (m, 1H), 3.50 (dd, 1H, J=9.6, 11.0 Hz), 2.34 (s, 3H), 2.10 (s, 3H), 2.07 (s, 3H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 170.45, 169.18, 158.52, 139.10, 135.98, 133.41, 129.83, 128.72, 128.20, 127.86, 127.73, 86.89, 79.82, 77.17, 67.42, 62.22, 60.19, 47.52, 21.14, 20.71, 20.62; HRMS (ESI) calcd for $C_{25}H_{28}NO_7S$ $[M+H]^+$: 486.1581, found: 486.1571.

4.3. Glycosylations of donors 1b–1g with acceptor 6a

General procedure: Triflic anhydride (11.8 μL, 0.070 mmol, 1.3 equiv) was added to a stirred solution of **1b**–**1g** (1.2 equiv), BSM (15.9 mg, 0.075 mol, 1.4 equiv) and activated 4 Å molecular sieves (400 mg) in CH_2Cl_2 (5.0 mL) at low temperature under nitrogen atmosphere. The reaction mixture was stirred for 5–20 min, after loss of donor detected by TLC, a solution of the acceptor alcohol **6a** (20.0 mg, 0.054 mmol, 1.0 equiv) in CH_2Cl_2 (0.5 mL) was added dropwise to the pre-activated system. The mixture was stirred and warmed to room temperature slowly, and then quenched by Et_3N (0.1 mL). The precipitate was filtered off and the filtrate was concentrated. The residue was purified by column chromatography on silica gel to give **7b**, 7**c**, **7e** and **7g**.

4.3.1. Coupling of **1b** with **6a** to give methyl (2-amino-2,3-N,O-carbonyl-4,6-diacetyl-2-deoxy-α- and β-D-glucopyranosyl)-(1→3)-2-O-benzyl-4,6-O-benzylidene-α-D-glucopyranosides (**7bα**) and (**7bβ**)

Donor **1b** was pre-activated at −73 °C, and then the reaction mixture was quenched by Et_3N at −60 °C. The crude product was purified by column chromatography (petroleum ether/ethyl acetate, 3:1 to 1.5:1) to give **7b**, yield=87% (α/β=1:2). R_f (α-isomer)=0.25, R_f (β-isomer)=0.20 (petroleum ether/ethyl acetate, 1:1); compound **7bα**: ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.36–7.41 (m, 10H), 5.49 (s, 1H), 5.44 (d, 1H, J=2.5 Hz, H-1′), 5.23 (t, 1H, J=10.0 Hz), 4.83 (s, 1H), 4.73 (d, 1H, J=3.5 Hz, H-1), 4.59–4.66 (m, 3H), 4.27 (t, 1H, J=9.5 Hz), 4.26 (dd, 1H, J=4.5, 10.5 Hz), 4.12–4.15 (m, 1H), 4.00 (dd, 1H, J=2.0, 12.5 Hz), 3.94 (dd, 1H, J=4.0, 12.5 Hz), 3.83 (dt, 1H, J=5.0, 10.0 Hz), 3.71 (t, 1H, J=10.5 Hz), 3.56–3.63 (m, 3H), 3.41 (s, 3H), 2.06 (s, 6H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 170.63, 169.15, 158.47, 137.35, 136.95, 129.50, 128.61, 128.57, 128.32, 126.09, 101.92, 98.28, 95.29, 82.20, 77.67, 76.08, 74.41, 72.84, 70.04, 69.00, 68.10, 61.90, 61.26, 58.47, 55.40, 20.68 (2C); HRMS (ESI) calcd for $C_{32}H_{37}NO_{13}Na$ $[M+Na]^+$: 666.2157, found: 666.2155. Compound **7bβ**: ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.33–7.47 (m, 10H), 5.52 (s, 1H), 5.30 (s, 1H), 5.24 (dd, 1H, J=9.0, 10.0 Hz), 4.88 (d, 1H, J=8.0 Hz, H-1′), 4.67 (d, 1H, J=11.5 Hz), 4.66 (d, 1H, J=4.0 Hz, H-1), 4.64 (d, 1H, J=11.5 Hz), 4.25 (dd, 1H, J=5.0, 10.0 Hz), 4.09–4.19 (m, 3H), 4.04 (dd, 1H, J=10.5, 12.0 Hz), 3.79 (dt, 1H, J=4.5, 10.0 Hz), 3.71 (t, 1H, J=10.0 Hz), 3.62–3.66 (m, 1H), 3.58 (dd, 1H, J=3.5, 9.5 Hz), 3.56 (t, 1H, J=9.5 Hz), 3.43 (dd, 1H, J=7.5, 12.0 Hz), 3.39 (s, 3H), 2.08 (s, 3H), 1.98 (s, 3H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 170.63, 169.15, 158.22, 137.11, 137.03, 129.06, 128.83, 128.69, 128.33, 128.18, 125.92, 101.85, 101.19, 98.27, 79.79, 79.26, 78.95, 76.62, 74.76, 73.53, 68.80, 67.49, 62.40, 62.18, 59.93, 55.41, 20.67, 20.63; MS (FAB) 644 $[M+H]^+$; Anal. Calcd for $C_{32}H_{37}NO_{13}$: C, 59.71; H, 5.79; N, 2.18. Found: C, 60.06; H, 5.66; N, 1.99.

4.3.2. Coupling of **1c** with **6a** to give methyl (N-benzyl-2-amino-2,3-N,O-carbonyl-4,6-dibenzyl-2-deoxy-β-D-glucopyranosyl)-(1→3)-2-O-benzyl-4,6-O-benzylidene-α-D-glucopyranoside (**7c**)

Donor **1c** was pre-activated at −73 °C. The crude product was purified by column chromatography (petroleum ether/ethyl acetate, 6:1) to give **7c**, yield=85%. R_f=0.40 (petroleum ether/ethyl acetate, 2:1); ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.39–7.46 (m, 4H), 7.13–7.34 (m, 21H), 5.48 (s, 1H), 5.11 (d, 1H, J=8.0 Hz, H-1′), 4.77 (d, 1H, J=11.5 Hz), 4.69 (d, 1H, J=3.5 Hz, H-1), 4.54 (d, 1H, J=15.0 Hz), 4.49 (s, 2H), 4.45 (d, 1H, J=11.0 Hz), 4.37 (d, 1H, J=14.5 Hz), 4.36 (d, 1H, J=12.0 Hz), 4.36 (t, 1H, J=9.0 Hz), 4.31 (d, 1H, J=12.0 Hz), 4.26 (dd, 1H, J=4.5, 10.0 Hz), 3.98 (dd, 1H, J=10.0, 12.0 Hz), 3.82 (dd, 1H, J=4.5, 10.0 Hz), 3.78 (dd, 1H, J=8.5, 9.5 Hz), 3.72 (t, 1H, J=10.0 Hz), 3.60–3.65 (m, 2H), 3.58 (dd, 1H, J=4.0, 11.0 Hz), 3.54 (dd, 1H, J=2.0, 11.0 Hz), 3.39–3.42 (m, 1H), 3.36 (s, 3H), 3.27 (dd, 1H, J=8.0, 12.0 Hz); ^{13}C NMR (125 MHz, $CDCl_3$) δ 159.23, 138.24, 137.41, 137.24, 137.17, 135.73, 129.49, 128.98, 128.59, 128.50, 128.32, 128.20, 128.14, 127.94, 127.81, 127.43, 126.14, 101.66, 100.96, 97.86, 80.74, 80.58, 79.69, 77.16, 74.76, 74.19, 73.46, 72.94, 72.61, 68.97, 68.19, 62.28, 60.41, 55.28, 47.84; MS (FAB) 829 $[M]^+$; Anal. Calcd for $C_{49}H_{51}NO_{11}$: C, 70.91; H, 6.19; N, 1.69. Found: C, 70.80; H, 6.25; N, 1.64.

*4.3.3. Coupling of **1e** with **6a** to give methyl (N-acetyl-2-amino-2,3-N,O-carbonyl-4,6-dibenzyl-2-deoxy-D-glucopyranosyl)-(1→3)-2-O-benzyl-4,6-O-benzylidene-α-D-glucopyranoside (**7e**)*

Donor **1e** was pre-activated at −60 °C. The crude product was purified by column chromatography (petroleum ether/ethyl acetate, 4:1) to give **7e** as an inseparable anomeric mixture, and anomeric ratio was determined by integration of the ^{1}H NMR spectrum of the reaction mixture, yield=84% (α/β=1:1). R_f=0.30 (petroleum ether/ethyl acetate, 1.5:1); ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.40–7.46 (m, 4H), 7.25–7.36 (m, 20H), 7.14 (t, 1H, *J*=7.0 Hz), 7.00 (t, 2H, *J*=7.5 Hz), 6.65 (d, 2H, *J*=7.5 Hz), 5.52 (s, 0.8H), 5.40 (s, 1H), 5.36 (d, 1H, *J*=3.0 Hz, H-1′α), 5.08 (d, 0.7H, *J*=7.5 Hz, H-1′β), 4.84 (d, 1H, *J*=12.0 Hz), 4.81 (d, 0.8H, *J*=12.0 Hz), 4.72 (d, 1.7H, *J*=4.0 Hz, H-1), 4.49–4.67 (m, 8H), 4.23–4.34 (m, 4H), 4.13–4.15 (m, 2H), 4.03 (d, 2H, *J*=4.0 Hz), 4.00 (dd, 0.8H, *J*=10.0, 12.0 Hz), 3.80–3.88 (m, 1.8H), 3.53–3.77 (m, 8H), 3.44–3.48 (m, 1H), 3.41 (s, 3H), 3.36 (s, 2.2H), 3.25 (dd, 0.7H, *J*=7.5, 11.5 Hz, H-2′β), 3.01 (dd, 1H, *J*=3.0, 12.0 Hz, H-2′α), 1.88 (s, 3H), 1.80 (s, 2H); HRMS (ESI) calcd for $C_{44}H_{47}NO_{12}Na$ $[M+Na]^+$: 804.2990, found: 804.2994.

*4.3.4. Coupling of **1g** with **6a** to give methyl (N-benzyl-2-amino-2,3-N,O-carbonyl-4,6-diacetyl-2-deoxy-α- and β-D-glucopyranosyl)-(1→3)-2-O-benzyl-4,6-O-benzylidene-α-D-glucopyranosides (**7gα**) and (**7gβ**)*

Donor **1g** was pre-activated at −50 °C. The crude product was purified by column chromatography (petroleum ether/ethyl acetate, 7:1) to give **7g**, yield=94% (α/β=3:1). R_f (α-isomer)=0.45, R_f (β-isomer)=0.40 (petroleum ether/ethyl acetate, 1:1); compound **7gα**: ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.42–7.44 (m, 2H), 7.31–7.39 (m, 8H), 7.13–7.16 (m, 1H), 6.97–7.00 (m, 2H), 6.61–6.63 (m, 2H), 5.44 (s, 1H), 5.38 (d, 1H, *J*=3.0 Hz, H-1′), 5.06 (t, 1H, *J*=10.0 Hz), 4.78 (d, 1H, *J*=4.0 Hz, H-1), 4.67 (d, 1H, *J*=15.0 Hz), 4.65 (d, 1H, *J*=11.0 Hz), 4.57 (d, 1H, *J*=11.0 Hz), 4.50 (dd, 1H, *J*=10.0, 12.0 Hz), 4.29 (t, 1H, *J*=9.5 Hz), 4.26 (dd, 1H, *J*=5.0, 10.5 Hz), 4.15–4.18 (m, 1H), 3.92 (dd, 1H, *J*=2.0, 12.5 Hz), 3.86–3.90 (m, 1H), 3.83 (dd, 1H, *J*=4.0, 12.5 Hz), 3.71 (t, 1H, *J*=10.5 Hz), 3.64 (d, 1H, *J*=15.0 Hz), 3.60 (t, 1H, *J*=9.5 Hz), 3.58 (dd, 1H, *J*=3.5, 9.5 Hz), 3.44 (s, 3H), 3.09 (dd, 1H, *J*=3.0, 12.0 Hz), 2.03 (s, 3H), 2.01 (s, 3H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 170.58, 169.09, 158.09, 137.13, 136.85, 134.34, 129.80, 128.64, 128.58, 128.46, 128.36, 128.30, 127.78, 126.66, 102.75, 98.04, 94.52, 82.19, 77.58, 73.73, 73.54, 72.55, 70.15, 69.01, 68.00, 61.93, 61.06, 59.23, 55.39, 46.86, 20.62 (2C); HRMS (ESI) calcd for $C_{39}H_{43}NO_{13}Na$ $[M+Na]^+$: 756.2627, found: 756.2629. Compound **7gβ**: ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.45–7.47 (m, 2H), 7.41–7.43 (m, 2H), 7.28–7.37 (m, 11H), 5.54 (s, 1H), 5.13 (dd, 1H, *J*=8.5, 10.5 Hz), 5.10 (d, 1H, *J*=7.5 Hz, H-1′), 4.74 (d, 1H, *J*=3.5 Hz, H-1), 4.56 (d, 1H, *J*=14.5 Hz), 4.53 (s, 2H), 4.32 (t, 1H, *J*=9.5 Hz), 4.30 (d, 1H, *J*=14.5 Hz), 4.27 (dd, 1H, *J*=4.5, 10.0 Hz), 4.08 (dd, 1H, *J*=5.0, 12.5 Hz), 4.01 (dd, 1H, *J*=2.5, 12.5 Hz), 3.96 (dd, 1H, *J*=10.0, 12.0 Hz), 3.84 (dt, 1H, *J*=4.5, 10.0 Hz), 3.76 (t, 1H, *J*=10.0 Hz), 3.68 (dd, 1H, *J*=3.5, 9.5 Hz), 3.58 (t, 1H, *J*=9.5 Hz), 3.52–3.55 (m, 1H), 3.33–3.38 (m, 1H), 3.36 (s, 3H), 2.05 (s, 3H), 1.93 (s, 3H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 170.58, 169.15, 158.39, 137.14, 135.22, 129.52, 129.10, 128.64, 128.42, 128.18, 128.12, 128.02, 126.04, 101.63, 101.34, 97.79, 80.42, 79.37, 75.86, 74.26, 72.60, 68.90, 67.68, 62.35, 62.10, 60.37, 60.03, 55.30, 47.84, 21.03, 20.64; HRMS (ESI) calcd for $C_{39}H_{43}NO_{13}+NH_4$ $[M+NH_4]^+$: 751.3073, found: 751.3074.

4.4. Glycosylations of 1c with 6a–6m by means of BSM/Tf_2O pre-activation

General procedure: Triflic anhydride (11.8 μL, 0.070 mmol, 1.3 equiv) was added to a stirred solution of **1c** (37.6 mg, 0.065 mmol, 1.2 equiv), BSM (15.9 mg, 0.075 mmol, 1.4 equiv) and activated 4 Å molecular sieves (500 mg) in CH_2Cl_2 (6.0 mL) at −73 °C under nitrogen atmosphere. The reaction mixture was stirred for 3–5 min, after disappearance of **1c** detected by TLC, a solution of the acceptor alcohol **6a** (25.0 mg, 0.054 mmol, 1.0 equiv) or **6b–6m** in CH_2Cl_2 (0.5 mL) was added dropwise to the pre-activated system. The mixture was stirred and slowly warmed to room temperature, and then quenched by Et_3N (0.1 mL). The precipitate was filtered off and the filtrate was concentrated. The crude product was purified by column chromatography on silica gel to give **7c** and **8b–8m**.

*4.4.1. Coupling of **1c** with **6b** to give methyl (N-benzyl-2-amino-2,3-N,O-carbonyl-4,6-dibenzyl-2-deoxy-β-D-glucopyranosyl)-(1→2)-3-O-benzyl-4,6-O-benzylidene-α-D-glucopyranoside (**8b**)*

The crude product was purified by column chromatography (petroleum ether/ethyl acetate, 7:1) to give **8b**, yield=83%. R_f=0.50 (petroleum ether/ethyl acetate, 2:1); ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.58–7.60 (m, 2H), 7.48–7.50 (m, 2H), 7.24–7.40 (m, 19H), 7.18–7.20 (m, 2H), 5.59 (s, 1H), 5.04 (d, 1H, *J*=8.0 Hz, H-1′), 5.00 (d, 1H, *J*=11.0 Hz), 4.85 (d, 1H, *J*=3.5 Hz, H-1), 4.80 (d, 1H, *J*=11.5 Hz), 4.63 (d, 1H, *J*=14.5 Hz), 4.56 (d, 1H, *J*=11.0 Hz), 4.52 (d, 1H, *J*=12.5 Hz), 4.45 (d, 1H, *J*=12.5 Hz), 4.44 (d, 1H, *J*=11.5 Hz), 4.34 (dd, 1H, *J*=5.0, 10.5 Hz), 4.20 (t, 1H, *J*=9.5 Hz), 4.18 (d, 1H, *J*=14.5 Hz), 3.88–3.97 (m, 3H), 3.78 (t, 1H, *J*=10.0 Hz), 3.71 (dd, 1H, *J*=3.0, 9.0 Hz), 3.60–3.68 (m, 3H), 3.49 (s, 3H), 3.45–3.48 (m, 1H), 3.14 (dd, 1H, *J*=7.5, 12.0 Hz); ^{13}C NMR (125 MHz, $CDCl_3$) δ 158.91, 137.93, 137.82, 137.25 (2C), 135.24, 130.47, 129.02, 128.50, 128.40, 128.37, 128.28, 128.04, 128.00, 127.94, 127.91, 127.74, 127.71, 125.95, 102.06, 101.40, 100.09, 83.19, 80.62, 78.43, 76.69, 76.17, 75.18, 73.93, 73.36, 73.00, 69.16, 68.31, 62.20, 59.63, 55.45, 47.68; MS (FAB) 829 $[M]^+$, 830 $[M+H]^+$; Anal. Calcd for $C_{49}H_{51}NO_{11}$: C, 70.91; H, 6.19; N, 1.69. Found: C, 71.11; H, 6.32; N, 1.50.

*4.4.2. Coupling of **1c** with **6c** to give methyl (N-benzyl-2-amino-2,3-N,O-carbonyl-4,6-dibenzyl-2-deoxy-β-D-glucopyranosyl)-(1→3)-2-O-benzyl-4,6-O-benzylidene-α-D-galactopyranoside (**8c**)*

The crude product was purified by column chromatography (petroleum ether/ethyl acetate, 3:1) to give **8c**, yield=83%. R_f=0.20 (petroleum ether/ethyl acetate, 2:1); ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.56–7.58 (m, 2H), 7.42–7.43 (m, 2H), 7.24–7.38 (m, 16H), 7.18–7.20 (m, 2H), 7.10 (t, 1H, *J*=7.5 Hz), 6.85 (t, 2H, *J*=7.5 Hz), 5.55 (s, 1H), 5.08 (d, 1H, *J*=8.0 Hz, H-1′), 4.89 (d, 1H, *J*=3.5 Hz, H-1), 4.80 (d, 1H, *J*=11.0 Hz), 4.59 (d, 2H, *J*=12.5 Hz), 4.55 (d, 1H, *J*=12.0 Hz), 4.53 (d, 1H, *J*=11.5 Hz), 4.44 (d, 1H, *J*=12.0 Hz), 4.43 (d, 1H, *J*=11.5 Hz), 4.34 (d, 1H, *J*=3.5 Hz), 4.28 (dd, 1H, *J*=3.5, 10.0 Hz), 4.21–4.26 (m, 2H), 4.19 (dd, 1H, *J*=3.5, 10.5 Hz), 4.00 (dd, 1H, *J*=1.5, 12.5 Hz), 3.98 (dd, 1H, *J*=10.0, 12.0 Hz), 3.72 (dd, 1H, *J*=9.0, 10.0 Hz), 3.64–3.67 (m, 3H), 3.53–3.56 (m, 1H), 3.38 (s, 3H), 3.18 (dd, 1H, *J*=8.0, 12.0 Hz); ^{13}C NMR (125 MHz, $CDCl_3$) δ 158.98, 137.96, 137.89, 137.50, 137.28, 135.10, 130.20, 129.11, 128.56, 128.36, 128.32, 128.23, 128.04, 128.02, 127.89, 127.68, 126.46, 102.75, 101.34, 98.16, 80.71, 76.75, 76.60, 76.59, 74.04, 73.76, 73.35, 72.97, 72.76, 69.23, 68.48, 62.54, 59.70, 55.47, 47.69; MS (FAB) 852 $[M+Na]^+$; Anal. Calcd for $C_{49}H_{51}NO_{11}$: C, 70.91; H, 6.19; N, 1.69. Found: C, 71.05; H, 6.66; N, 1.49.

*4.4.3. Coupling of **1c** with **6d** to give methyl (N-benzyl-2-amino-2,3-N,O-carbonyl-4,6-dibenzyl-2-deoxy-β-D-glucopyranosyl)-(1→2)-3-O-benzyl-4,6-O-benzylidene-α-D-galactopyranoside (**8d**)*

The crude product was purified by column chromatography (petroleum ether/ethyl acetate, 5:1) to give **8d**, yield=83%. R_f=0.3 (petroleum ether/ethyl acetate, 2:1); ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.53–7.59 (m, 4H), 7.23–7.36 (m, 18H), 7.17–7.19 (m, 2H), 5.46 (s, 1H), 5.02 (d, 1H, *J*=3.5 Hz, H-1), 4.97 (d, 1H, *J*=7.5 Hz, H-1′), 4.79 (d, 1H, *J*=11.5 Hz), 4.59 (d, 1H, *J*=15.0 Hz), 4.54 (d, 1H, *J*=11.5 Hz), 4.52 (d, 1H, *J*=12.0 Hz), 4.43 (d, 1H, *J*=10.0 Hz), 4.42 (d, 1H, *J*=12.5 Hz), 4.28–4.31 (m, 3H), 4.27 (d, 1H, *J*=14.5 Hz), 4.12 (dd, 1H, *J*=3.5, 10.0 Hz), 4.05 (dd, 1H, *J*=1.5, 12.5 Hz), 3.97 (dd, 1H, *J*=10.0, 12.0 Hz), 3.76 (t, 1H, *J*=9.5 Hz), 3.69 (s, 1H), 3.66 (dd, 1H, *J*=4.5, 11.5 Hz), 3.61 (dd, 1H, *J*=1.5, 10.5 Hz), 3.47–3.50 (m, 1H), 3.46 (s, 3H), 3.21 (dd, 1H,

J=8.0, 11.5 Hz); ^{13}C NMR (125 MHz, $CDCl_3$) δ 158.86, 137.86, 137.64, 137.60, 137.36, 135.36, 130.40, 128.92, 128.40, 128.33, 128.29, 128.13, 128.02, 127.93, 127.90, 128.81, 127.77, 127.71, 127.63, 126.20, 102.44, 101.10, 100.19, 80.73, 76.51, 75.94, 74.38, 73.82, 73.42, 73.25, 72.90, 70.89, 69.49, 68.17, 62.25, 59.54, 55.71, 47.31; MS (FAB) 852 $[M+Na]^+$, 868 $[M+K]^+$; Anal. Calcd for $C_{49}H_{51}NO_{11}$: C, 70.91; H, 6.19; N, 1.69. Found: C, 70.73; H, 6.18; N, 1.53.

4.4.4. Coupling of **1c** with **6e** to give methyl (N-benzyl-2-amino-2,3-N,O-carbonyl-4,6-dibenzyl-2-deoxy-β-D-glucopyranosyl)-(1→3)-2-O-benzyl-4,6-O-benzylidene-β-D-glucopyranoside (**8e**)

The crude product was purified by column chromatography (petroleum ether/ethyl acetate, 8:1) to give **8e**, yield=87%. R_f=0.30 (petroleum ether/ethyl acetate, 3:1); ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.40–7.43 (m, 4H), 7.16–7.32 (m, 21H), 5.49 (s, 1H), 5.04 (d, 1H, J=7.5 Hz, H-1′), 4.85 (d, 1H, J=11.5 Hz), 4.78 (d, 1H, J=11.0 Hz), 4.49 (d, 1H, J=14.5 Hz), 4.45 (d, 1H, J=11.5 Hz), 4.40 (d, 1H, J=7.5 Hz, H-1), 4.39 (d, 1H, J=11.0 Hz), 4.31–4.37 (m, 4H), 4.09 (t, 1H, J=9.5 Hz), 3.88 (dd, 1H, J=9.5, 12.0 Hz), 3.77 (t, 1H, J=10.5 Hz), 3.72 (dd, 1H, J=8.5, 9.5 Hz), 3.66 (t, 1H, J=9.5 Hz), 3.57–3.59 (m, 1H), 3.56 (s, 3H), 3.54 (dd, 1H, J=4.5, 11.0 Hz), 3.49 (dd, 1H, J=7.5, 8.0 Hz), 3.35–3.43 (m, 2H), 3.23 (dd, 1H, J=7.5, 11.5 Hz); ^{13}C NMR (125 MHz, $CDCl_3$) δ 159.20, 138.17, 137.87, 137.36, 137.12, 135.81, 129.32, 129.01, 128.50, 128.36, 128.26, 128.17, 127.97, 127.89, 127.85, 127.78, 127.51, 126.14, 105.08, 101.49, 100.34, 82.61, 80.61, 78.98, 77.17, 74.44, 74.21, 73.43, 72.90, 68.74, 68.47, 66.15, 60.51, 57.28, 47.90; MS (FAB) 853 $[M+Na+H]^+$; Anal. Calcd for $C_{49}H_{51}NO_{11}$: C, 70.91; H, 6.19; N, 1.69. Found: C, 71.11; H, 6.29; N, 1.42.

4.4.5. Coupling of **1c** with **6f** to give methyl (N-benzyl-2-amino-2,3-N,O-carbonyl-4,6-dibenzyl-2-deoxy-D-glucopyranosyl)-(1→2)-3-O-benzyl-4,6-O-benzylidene-β-D-glucopyranoside (**8f**)

The crude product was purified by column chromatography (petroleum ether/ethyl acetate, 4:1) to give **8f** as an inseparable anomeric mixture, and anomeric ratio was determined by integration of the ^{1}H NMR spectrum of the reaction mixture, yield=85% (α/β=1:2). R_f=0.30 (petroleum ether/ethyl acetate, 2:1); ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.46–7.49 (m, 3H), 7.11–7.40 (m, 33H), 7.03–7.06 (m, 2H), 5.59 (s, 0.5H), 5.58 (s, 1H), 5.52 (d, 0.6H, J=3.0 Hz, H-1a′), 5.06 (d, 1H, J=7.5 Hz, H-1b′), 4.96 (d, 1H, J=11.0 Hz), 4.93 (d, 0.6H, J=10.5 Hz), 4.81–4.87 (m, 2H), 4.59 (d, 1H, J=10.5 Hz), 4.57 (d, 1H, J=12.0 Hz), 4.44–4.51 (m, 5.5H), 4.37–4.41 (m, 2H), 4.33 (d, 0.7H, J=7.0 Hz, H-1a), 4.27 (d, 1H, J=14.5 Hz), 4.18 (d, 0.6H, J=12.0 Hz), 3.67–4.02 (m, 12H), 3.53 (s, 1.7H), 3.46 (s, 3H), 3.43–3.49 (m, 2H), 3.20–3.26 (m, 2H), 3.13 (dd, 0.7H); MS (FAB) 853 $[M+Na+H]^+$; Anal. Calcd for $C_{49}H_{51}NO_{11}$: C, 70.91; H, 6.19; N, 1.69. Found: C, 71.65; H, 6.66; N, 1.44.

4.4.6. Coupling of **1c** with **6g** to give methyl (N-benzyl-2-amino-2,3-N,O-carbonyl-4,6-dibenzyl-2-deoxy-α- and β-D-glucopyranosyl)-(1→3)-2-azide-4,6-O-benzylidene-2-deoxy-α-D-mannopyranosides (**8gα**) and (**8gβ**)

The crude product was purified by column chromatography (petroleum ether/ethyl acetate, 7:1) to give **8g**, yield=83% (α/β=1:1.5). R_f (α-isomer)=0.45, R_f (β-isomer)=0.40 (petroleum ether/ethyl acetate, 2:1); compound **8gα**: ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.44–7.46 (m, 2H), 7.25–7.34 (m, 11H), 7.15–7.21 (m, 3H), 7.06 (t, 2H, J=8.0 Hz), 6.72 (d, 2H, J=7.5 Hz), 5.49 (s, 1H), 5.29 (d, 1H, J=2.5 Hz, H-1′), 4.85 (d, 1H, J=11.5 Hz), 4.59–4.65 (m, 3H), 4.53 (d, 1H, J=12.0 Hz), 4.45 (d, 1H, J=11.0 Hz), 4.43 (d, 1H, J=12.5 Hz), 4.42 (dd, 1H, J=3.5, 10.0 Hz), 4.23–4.25 (m, 1H), 4.05 (t, 1H, J=9.0 Hz), 3.94 (dd, 1H, J=1.5, 3.5 Hz), 3.74–3.84 (m, 5H), 3.68 (d, 2H, J=2.5 Hz), 3.37 (s, 3H), 3.13 (dd, 1H, J=3.0, 12.5 Hz); ^{13}C NMR (125 MHz, $CDCl_3$) δ 158.61, 137.72, 137.40, 136.95, 134.80, 129.73, 128.63, 128.55, 128.36, 128.14, 128.02, 127.81, 127.74, 126.56, 102.93, 99.89, 96.16, 78.56, 76.90, 74.56, 74.28, 73.53, 73.48, 72.81, 68.71, 67.97, 63.80, 63.70, 59.06, 55.13, 46.62; MS (FAB) 764 $[M]^+$, 765 $[M+H]^+$; Anal. Calcd for $C_{42}H_{44}N_4O_{10}$: C, 65.96; H, 5.80; N, 7.33. Found: C, 65.69; H, 6.04; N, 7.09. Compound **8gβ**: ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.21–7.38 (m, 20H), 5.44 (s, 1H), 4.84 (d, 1H, J=8.0 Hz, H-1′), 4.81 (d, 1H, J=11.5 Hz), 4.69 (d, 1H, J=1.5 Hz, H-1), 4.48–4.56 (m, 3H), 4.43 (s, 2H), 4.16–4.18 (m, 1H), 4.13 (dd, 1H, J=4.0, 9.5 Hz), 4.03–4.09 (m, 2H), 3.70–3.79 (m, 4H), 3.50–3.55 (m, 2H), 3.37–3.41 (m, 1H), 3.35 (s, 3H), 3.32 (dd, 1H, J=4.0, 12.0 Hz); ^{13}C NMR (125 MHz, $CDCl_3$) δ 159.05, 138.07, 137.30, 137.16, 136.23, 129.22, 128.63, 128.36, 128.29, 128.17, 128.00, 127.90, 127.76, 127.64, 126.17, 102.04, 99.61, 98.70, 80.36, 77.54, 77.26, 74.01, 73.26, 73.17, 72.85, 68.62, 68.39, 63.54, 61.44, 60.96, 55.09, 47.90; MS (FAB) 764 $[M]^+$, 765 $[M+H]^+$; Anal. Calcd for $C_{42}H_{44}N_4O_{10}$: C, 65.96; H, 5.80; N, 7.33. Found: C, 65.69; H, 6.08; N, 7.10.

4.4.7. Coupling of **1c** with **6h** to give methyl (N-benzyl-2-amino-2,3-N,O-carbonyl-4,6-dibenzyl-2-deoxy-α- and β-D-glucopyranosyl)-(1→2)-3-azide-4,6-O-benzylidene-3-deoxy-α-D-glucopyranosides (**8hα**) and (**8hβ**)

The crude product was purified by column chromatography (petroleum ether/ethyl acetate, 4:1) to give **8h**, yield=83% (α/β=1:2). R_f (β-isomer)=0.40, R_f (α-isomer)=0.25 (petroleum ether/ethyl acetate, 2:1); compound **8hα**: ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.48–7.50 (m, 2H), 7.21–7.38 (m, 18H), 5.56 (s, 1H), 5.09 (d, 1H, J=3.0 Hz, H-1′), 4.93 (d, 1H, J=15.0 Hz), 4.89 (d, 1H, J=3.5 Hz, H-1), 4.87 (d, 1H, J=11.0 Hz), 4.68–4.72 (m, 1H), 4.56 (d, 1H, J=12.5 Hz), 4.48 (d, 1H, J=11.5 Hz), 4.42 (d, 1H, J=12.0 Hz), 4.32 (dd, 1H, J=5.0, 10.5 Hz), 4.01 (t, 1H, J=10.0 Hz), 3.98 (d, 1H, J=15.0 Hz), 3.91–3.94 (m, 2H), 3.85 (dt, 1H, J=5.0, 10.0 Hz), 3.75 (dd, 1H, J=2.5, 10.5 Hz), 3.73 (t, 1H, J=10.5 Hz), 3.59–3.63 (m, 2H), 3.50 (s, 3H), 3.46 (t, 1H, J=10.0 Hz), 3.30 (dd, 1H, J=3.0, 12.0 Hz); ^{13}C NMR (125 MHz, $CDCl_3$) δ 158.48, 137.64, 137.44, 136.65, 134.95, 129.16, 128.41, 128.37, 128.32, 128.07, 127.91, 127.82, 125.98, 101.59, 96.38, 91.84, 80.01, 77.39, 74.41, 73.80, 73.45, 73.38, 72.97, 68.81, 67.43, 62.48, 61.04, 59.05, 55.11, 47.12; HRMS (ESI) calcd for $C_{42}H_{48}N_4O_{10}$ $[M+NH_4]^+$: 782.3396, found: 728.3381. Compound **8hβ**: ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.48–7.54 (m, 4H), 7.21–7.40 (m, 16H), 5.60 (s, 1H), 4.92 (d, 1H, J=7.5 Hz, H-1′), 4.84 (d, 1H, J=12.5 Hz), 4.83 (d, 1H, J=4.0 Hz, H-1), 4.79 (d, 1H, J=15.0 Hz), 4.52 (d, 1H, J=12.0 Hz), 4.48 (d, 1H, J=12.0 Hz), 4.46 (d, 1H, J=12.5 Hz), 4.34 (d, 1H, J=14.5 Hz), 4.33 (dd, 1H, J=5.0, 10.0 Hz), 4.09–4.14 (m, 2H), 3.92 (dt, 1H, J=5.0, 10.0 Hz), 3.56–3.77 (m, 7H), 3.43 (s, 3H), 3.24 (dd, 1H, J=7.5, 11.5 Hz); ^{13}C NMR (125 MHz, $CDCl_3$) δ 158.85, 137.74, 137.19, 136.71, 135.32, 129.85, 129.07, 128.47, 128.42, 128.28, 128.06, 127.96, 127.89, 127.81, 127.71, 125.89, 102.24, 101.46, 99.60, 80.90, 80.42, 76.91, 76.60, 73.80, 73.38, 72.98, 69.06, 68.53, 62.37, 61.44, 59.89, 55.64, 47.67; HRMS (ESI) calcd for $C_{42}H_{48}N_5O_{10}$ $[M+NH_4]^+$: 782.3396, found: 782.3384.

4.4.8. Coupling of **1c** with **6i** to give N-benzyl-2-amino-2,3-N,O-carbonyl-4,6-dibenzyl-2-deoxy-D-glucopyranosyl-(1→6)-1,2:3,4-di-O-isopropylidene-α-D-galactopyranoside (**8i**)

The crude product was purified by column chromatography (petroleum ether/ethyl acetate, 5:1) to give **8i** as an inseparable anomeric mixture, and anomeric ratio was determined by integration of the ^{1}H NMR spectrum of the reaction mixture, yield=96% (α/β=1:11). R_f=0.35 (petroleum ether/ethyl acetate, 2:1); major isomer **8iβ**: ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.54–7.55 (m, 2H), 7.25–7.53 (m, 11H), 7.17–7.19 (m, 2H), 5.58 (d, 1H, J=5.0 Hz, H-1), 4.81 (d, 1H, J=11.0 Hz), 4.71 (d, 1H, J=14.5 Hz), 4.70 (d, 1H, J=8.0 Hz, H-1′), 4.61 (d, 1H, J=5.0, 8.0 Hz), 4.57 (d, 1H, J=12.5 Hz), 4.46 (d, 1H, J=11.0 Hz), 4.43 (d, 1H, J=11.0 Hz), 4.41 (d, 1H, J=12.5 Hz), 4.22 (dd, 1H, J=2.0, 5.0 Hz), 4.19 (dd, 1H, J=2.0, 8.0 Hz), 4.15 (dd, 1H, J=2.0, 11.0 Hz), 4.08–4.13 (m, 2H), 4.07 (dd, 1H, J=9.5, 12.0 Hz), 3.79 (dd, 1H, J=8.5, 9.5 Hz), 3.72–3.76 (m, 1H), 3.69 (dd, 1H, J=3.0, 11.5 Hz), 3.53–3.56 (m, 1H), 3.22 (dd, 1H, J=8.0, 12.0 Hz), 1.48 (s, 3H), 1.47 (s,

3H), 1.32 (s, 3H), 1.29 (s, 3H); MS (FAB) 718 $[M+H]^+$; Anal. Calcd for $C_{40}H_{47}NO_{11}$: C, 66.93; H, 6.60; N, 1.95. Found: C, 67.02; H, 6.72; N, 1.91.

*4.4.9. Coupling of **1c** with **6j** to give methyl (N-benzyl-2-amino-2,3-N,O-carbonyl-4,6-dibenzyl-2-deoxy-D-glucopyranosyl)-(1→6)-2,3,4-tri-O-benzyl-α-D-glucopyranoside (**8j**)*

The crude product was purified by column chromatography (petroleum ether/ethyl acetate, 4:1) to give **8j** as an inseparable anomeric mixture, and anomeric ratio was determined by integration of the ^1H NMR spectrum of the reaction mixture, yield=85% (α/β=1:6). R_f=0.25 (petroleum ether/ethyl acetate, 2:1); major isomer **8jβ**: ^1H NMR (500 MHz, $CDCl_3$) δ 7.42–7.44 (m, 2H), 7.17–7.35 (m, 28H), 4.98 (d, 1H, *J*=11.0 Hz), 4.85 (d, 1H, *J*=11.5 Hz), 4.81 (d, 1H, *J*=11.5 Hz), 4.80 (d, 1H, *J*=10.5 Hz), 4.78 (d, 1H, *J*=11.0 Hz), 4.62 (d, 1H, *J*=12.0 Hz), 4.58 (d, 1H, *J*=15.0 Hz), 4.55 (d, 1H, *J*=3.5 Hz, H-1), 4.54 (d, 1H, *J*=10.5 Hz), 4.52 (d, 1H, *J*=10.0 Hz), 4.48 (d, 1H, *J*=15.0 Hz), 4.45 (d, 1H, *J*=11.0 Hz), 4.38 (d, 1H, *J*=7.5 Hz, H-1′), 4.31 (d, 1H, *J*=14.5 Hz), 4.01 (t, 1H, *J*=12.0 Hz), 3.99–4.04 (m, 2H), 3.82–3.85 (m, 1H), 3.73 (dd, 1H, *J*=8.5, 9.5 Hz), 3.62–3.66 (m, 2H), 3.51 (dd, 1H, *J*=5.5, 11.0 Hz), 3.46 (dd, 1H, *J*=3.5, 10.0 Hz), 3.47–3.50 (m, 1H), 3.34 (dd, 1H, *J*=9.0, 10.0 Hz), 3.33 (s, 3H), 3.22 (dd, 1H, *J*=7.5, 12.0 Hz); MS (ESI) 939 $[M+NH_4]^+$, 944 $[M+Na]^+$, 960 $[M+K]^+$; Anal. Calcd for $C_{56}H_{59}NO_{11}$: C, 72.94; H, 6.45; N, 1.52. Found: C, 72.67; H, 6.44; N, 1.55.

*4.4.10. Coupling of **1c** with **6k** to give N-benzyl-2-amino-2,3-N,O-carbonyl-4,6-dibenzyl-1-O-octyl-2-deoxy-α- and β-D-glucopyranosides (**8kα**) and (**8kβ**)*

The crude product was purified by column chromatography (petroleum ether/ethyl acetate, 11:1 to 9:1) to give **8k**, yield=95% (α/β=1:3.5). R_f(β-isomer)=0.7, R_f(α-isomer)=0.5 (petroleum ether/ethyl acetate, 2:1); compound **8kα**: ^1H NMR (500 MHz, $CDCl_3$) δ 7.20–7.35 (m, 14H), 4.86 (d, 1H, *J*=11.0 Hz), 4.68 (d, 1H, *J*=3.0 Hz, H-1), 4.64 (dd, 1H, *J*=10.0, 12.0 Hz), 4.56 (d, 1H, *J*=12.5 Hz), 4.47 (d, 1H, *J*=11.0 Hz), 4.42 (d, 1H, *J*=12.0 Hz), 4.41 (s, 2H), 3.90 (t, 1H, *J*=9.0 Hz), 3.72 (dd, 1H, *J*=3.5, 10.5 Hz), 3.65–3.67 (m, 1H), 3.59 (dd, 1H, *J*=1.5, 10.5 Hz), 3.46–3.51 (m, 1H), 3.31 (dd, 1H, *J*=3.0, 12.0 Hz), 3.00–3.05 (m, 1H), 1.46 (s, 2H), 1.26–1.32 (m, 10H), 0.88 (t, 3H, *J*=6.5 Hz); ^{13}C NMR (125 MHz, $CDCl_3$) δ 159.14, 137.78, 137.45, 135.31, 128.75, 128.63, 128.36, 128.13, 128.04, 127.84, 127.75, 95.17, 77.38, 74.88, 73.46, 73.00, 72.42, 68.65, 67.72, 61.24, 48.64, 31.80, 29.31, 29.17, 26.06, 22.62, 14.07; MS (ESI) 588 $[M+H]^+$, 605 $[M+NH_4]^+$, 610 $[M+Na]^+$; Anal. Calcd for $C_{36}H_{45}NO_6$: C, 73.57; H, 7.72; N, 2.38. Found: C, 73.41; H, 7.47; N, 2.36. Compound **8kβ**: ^1H NMR (500 MHz, $CDCl_3$) δ 7.39–7.41 (m, 2H), 7.25–7.34 (m, 11H), 7.21–7.23 (m, 2H), 4.84 (d, 1H, *J*=11.0 Hz), 4.57 (d, 1H, *J*=12.0 Hz), 4.56 (d, 1H, *J*=7.5 Hz, H-1), 4.51 (d, 1H, *J*=15.0 Hz), 4.50 (d, 1H, *J*=12.5 Hz), 4.49 (d, 1H, *J*=15.0 Hz), 4.46 (d, 1H, *J*=12.0 Hz), 4.11 (dd, 1H, *J*=9.5, 12.0 Hz), 3.81–3.86 (m, 1H), 3.79 (dd, 1H, *J*=8.0, 9.5 Hz), 3.71 (dd, 1H, *J*=2.0, 11.0 Hz), 3.67 (dd, 1H, *J*=5.0, 11.0 Hz), 3.55–3.58 (m, 1H), 3.28–3.33 (m, 1H), 3.26 (dd, 1H, *J*=7.0, 12.0 Hz), 1.55–1.57 (m, 2H), 1.26–1.30 (m, 10H), 0.88 (t, 3H, *J*=7.0 Hz); ^{13}C NMR (125 MHz, $CDCl_3$) δ 159.13, 137.98, 137.33, 136.15, 128.80, 128.47, 128.39, 128.01, 127.91, 127.74, 127.68, 101.59, 80.85, 76.75, 74.17, 73.45, 73.00, 69.78, 68.52, 60.72, 47.84, 31.78, 29.47, 29.32, 29.21, 26.04, 22.63, 14.08; MS (FAB) 587 $[M]^+$, 588 $[M+H]^+$; Anal. Calcd for $C_{36}H_{45}NO_6$: C, 73.57; H, 7.72; N, 2.38. Found: C, 73.79; H, 8.00; N, 2.58.

*4.4.11. Coupling of **1c** with **6l** to give N-benzyl-2-amino-2,3-N,O-carbonyl-4,6-dibenzyl-1-O-(N-carbobenzyloxy-L-serine methyl ester)-2-deoxy-D-glucopyranoside (**8l**)*

The crude product was purified by column chromatography (petroleum ether/ethyl acetate, 3:1) to give **8l** as an inseparable anomeric mixture, and anomeric ratio was determined by integration of the ^1H NMR spectrum of the reaction mixture, yield=98% (α/β=1:3). R_f=0.25 (petroleum ether/ethyl acetate, 1:1); major isomer **8lβ**: ^1H NMR (500 MHz, $CDCl_3$) δ 7.21–7.35 (m, 20H), 5.53 (d, 1H, *J*=7.5 Hz), 5.10 (d, 1H, *J*=15.5 Hz), 5.09 (d, 1H, *J*=15.5 Hz), 4.83 (d, 1H, *J*=11.0 Hz), 4.51 (d, 1H, *J*=8.0 Hz, H-1), 4.40–4.49 (m, 5H), 4.03–4.09 (m, 2H), 3.73–3.82 (m, 2H), 3.70 (s, 3H), 3.63–3.65 (m, 3H), 3.50–3.52 (m, 1H), 3.21 (dd, 1H, *J*=8.0, 12.0 Hz); HRMS (ESI) calcd for $C_{40}H_{43}N_2O_{10}$ $[M+H]^+$: 711.2912, found: 711.2976.

*4.4.12. Coupling of **1c** with **6m** to give methyl (N-benzyl-2-amino-2,3-N,O-carbonyl-4,6-dibenzyl-2-deoxy-D-glucopyranosyl)-(1→4)-2,3,6-tri-O-benzyl-α-D-glucopyranoside (**8m**)*

The crude product was purified by column chromatography (petroleum ether/ethyl acetate, 5:1) to give **8m** as an inseparable anomeric mixture, and anomeric ratio was determined by integration of the ^1H NMR spectrum of the mixture, yield=82% (α/β=2.5:1). R_f=0.3 (petroleum ether/ethyl acetate, 2:1); ^1H NMR (500 MHz, $CDCl_3$) δ 7.03–7.35 (m, 56H), 5.54 (d, 1H, *J*=3.0 Hz, H-1′α), 5.08 (d, 1H, *J*=12.0 Hz), 5.02 (d, 0.7H, *J*=12.0 Hz), 3.87–4.05 (m, 6H), 3.73–3.84 (m, 4H), 3.67–3.70 (m, 1H), 3.41–3.63 (m, 8H), 3.38 (s, 3H), 3.35 (s, 3H), 3.27–3.30 (m, 1H), 3.17 (dd, 0.9H, *J*=3.0, 12.0 Hz, H-2′α), 3.01 (dd, 0.4H, *J*=7.5, 12.0 Hz, H-2′β); MS (FAB) 921 $[M]^+$; Anal. Calcd for $C_{56}H_{59}NO_{11}$: C, 72.94; H, 6.45; N, 1.52. Found: C, 72.75; H, 6.29; N, 1.43.

4.5. Deprotection of disaccharide 8d

*4.5.1. Methyl (N-benzyl-2-amino-4,6-O-dibenzyl-2-deoxy-β-D-glucopyranosyl)-(1→2)-3-O-benzyl-4,6-O-benzylidene-α-D-galactopyranoside (**9**)*

Compound **8d** (50.0 mg, 0.066 mmol, 1.0 equiv) was dissolved in DMSO (2.0 mL) and stirred, and then *t*-BuOK (34.0 mg, 0.30 mmol, 5.0 equiv) was added. The reaction mixture was stirred at room temperature for 20 min, diluted with ethyl acetate and washed with water. The aqueous layer was extracted with ethyl acetate (3×2 mL). The combined organic layer was dried, filtered and concentrated under reduced pressure. The residue was purified by column chromatography (petroleum ether/ethyl acetate, 1:1) to give **9** (44 mg, 90%) as a white solid: ^1H NMR (500 MHz, $CDCl_3$) δ 7.55–7.57 (m, 2H), 7.23–7.37 (m, 20H), 7.18–7.20 (m, 3H), 5.54 (s, 1H), 4.84 (d, 1H, *J*=11.0 Hz), 4.77 (d, 1H, *J*=3.5 Hz, H-1), 4.71 (d, 1H, *J*=8.0 Hz, H-1′), 4.49–4.61 (m, 5H), 4.38 (d, 1H, *J*=3.5 Hz), 4.23 (dd, 1H, *J*=3.5, 10.5 Hz), 4.20 (dd, 1H, *J*=1.0, 12.5 Hz), 4.12 (dd, 1H, *J*=3.0, 10.0 Hz), 4.07 (d, 1H, *J*=13.0 Hz), 3.99 (d, 1H, *J*=13.0 Hz), 3.96 (dd, 1H, *J*=1.5, 12.5 Hz), 3.73 (dd, 1H, *J*=2.0, 11.0 Hz), 3.68 (dd, 1H, *J*=5.0, 11.0 Hz), 3.61 (s, 1H), 3.38–3.50 (m, 3H), 3.36 (s, 3H), 3.22 (br, 1H), 2.53 (dd, 1H, *J*=8.0, 9.0 Hz), 1.67 (br.s, 1H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 140.27, 138.37, 138.23, 138.03, 137.98, 128.72, 128.51, 128.33, 128.18, 128.02, 127.93, 127.76, 127.68, 127.62, 126.88, 126.18, 104.86, 100.60, 98.54, 78.10, 76.82, 75.73, 74.61, 74.24, 73.90, 73.37, 72.94, 69.26, 69.19, 62.70, 62.37, 55.43, 51.56, 42.65; HRMS (ESI) calcd for $C_{48}H_{54}NO_{10}$ $[M+H]^+$: 804.3742, found: 804.3759.

*4.5.2. Methyl (2-amino-2-deoxy-β-D-glucopyranosyl)-(1→2)-α-D-galactopyranoside (**10**)*

Compound **9** (44.0 mg, 0.055 mmol) was dissolved in THF/water (2:1, 3.0 mL) containing HOAc (0.15 mL), and 10% Pd/C (15.0 mg) was added. The mixture was hydrogenated under an atmospheric pressure of hydrogen. After stirring for 24 h, the catalyst was removed by filtration and the filtrate was concentrated. The residue was subjected to a C-18 reverse phase column chromatography (H_2O) to give **13** (18.0 mg, 95%) as a white solid after lyophilization: ^1H NMR (300 MHz, D_2O) δ 4.89 (d, 1H, *J*=3.5 Hz, H-1), 4.49 (d, 1H, *J*=8.5 Hz, H-1′), 3.72–3.82 (m, 5H), 3.56–3.62 (m, 3H), 3.25–3.31 (m, 3H), 3.23 (s, 3H), 2.65 (t, 1H, *J*=9.0 Hz); ^{13}C NMR (125 MHz, D_2O) δ 106.11, 101.55, 80.78, 78.61, 77.27, 73.18, 72.19, 71.98, 70.98, 63.77,

63.26, 59.04, 57.34; HRMS (ESI) calcd for $C_{13}H_{26}NO_{10}$ $[M+H]^+$: 356.1551, found: 356.1554.

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Supplementary data

^1H and ^{13}C NMR spectra of all new compounds. Supplementary data associated with this article can be found in the online version, at doi:10.1016/j.tet.2008.03.103.

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